Update on MiniBooNE

H. A. Tanaka [a]

[a]Department of Physics, Joseph Henry Laboratories
Princeton University
Princeton, New Jersey 08544, USA

MiniBooNE (Booster Neutrino Experiment) is searching for $\nu_\mu \to \nu_e$ oscillations in the neutrino beam produced by the 8 GeV Booster synchrotron at Fermilab. The Booster has delivered 3.66×10^{20} protons-on-target with over 380 thousand neutrino recorded in the detector since September 2002. MiniBooNE is now accumulating enough data to achieve its goal of conclusively confirming or refuting the evidence for neutrino oscillations observed by the LSND experiment.

1. Introduction

The MiniBooNE detector is a 610 cm radius sphere filled with mineral oil instrumented with photomultipliers. The detector is divided into two optically isolated concentric regions; an outer veto region with 240 photomultipliers and an inner "tank" region with 1280 photomultipliers. Neutrino interactions are detected via the Cherenkov radiation and scintillation light produced by charged particles passing through the mineral oil. The veto detects charged particles entering or exiting the tank region and is used to reject cosmic muons and select contained neutrino interactions.

The neutrino beam is produced by protons from the 8 GeV Booster synchrotron at FNAL. At design intensity, 5×10^{12} protons are extracted to the MiniBooNE beamline in a 1.6 μ sec pulse at a rate of 5 Hz. The beam is incident on a beryllium target inserted inside a magnetic horn, where secondary pions and kaons are produced and focussed into the 50 meter-long decay region. The subsequent decay of the secondary particles produce a nearly pure ν_μ beam, with average energy of 800 MeV and $\mathcal{O}(10^{-3})$ ν_e contamination. The small ν_e content is important for the sensitive search for $\nu_\mu \to \nu_e$ oscillation that is the goal of the experiment. The expected neutrino energy distribution at the detector is shown in Figure 1. In this energy range, the cross section for neutrino interactions are dominated by the charged current quasi-elastic interaction (CCQE), which comprise about 40% of the events. Neutral current elastic scattering and resonant single pion production (both neutral and charged current) comprise nearly the rest.

2. Physics

The primary physics goal of MiniBooNE is to confirm the evidence for $\overline{\nu}_\mu \to \overline{\nu}_e$ oscillations observed by the LSND experiment [1]. The evidence suggests a Δm^2 ranging from $10^{-1} - 10^{1}\,\mathrm{eV}^2$, with $\sim 0.25\%$ oscillation probability. The 540 meter distance of the detector from the target is chosen to reproduce the L/E distribution of the $\overline{\nu}_e$ excess in the LSND experiment ($\sim 1\mathrm{m}/\,\mathrm{MeV}$) and maximize the sensitivity of the experiment to these oscillations.
The phenomena of neutrino oscillations, considered speculative only a decade ago, are now definitively established in two modes: the "solar" $\nu_e \to \nu_x$ oscillations with $\Delta m^2 \sim 8 \times 10^{-5}\,\mathrm{eV}^2$ and large (but not maximal) mixing [2][3][4][5][6], and the "atmospheric" $\nu_\mu \to \nu_x$ oscillations with $\Delta m^2 \sim 2.5 \times 10^{-3}\,\mathrm{eV}^2$ and maximal mixing [7][8][9].

The evidence for oscillations reported by LSND, however, remains unconfirmed by other experiments. Its place in the phenomenology of neutrino oscillations is intriguing, since the

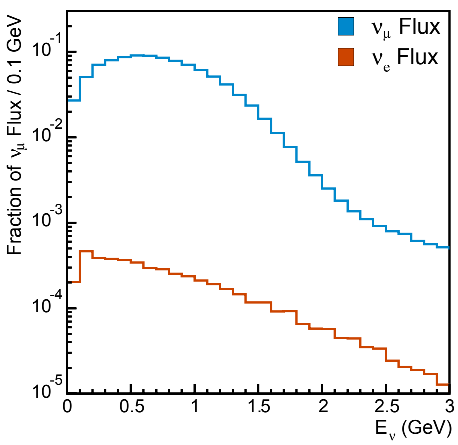

Figure 1. Energy distribution of neutrinos at MiniBooNE obtained from Monte Carlo simulation.

three known active flavors of neutrinos are unable to simultaneously accommodate the three Δm^2 regimes observed by the experiments. A drastic remedy to the Standard Model (minimally extended to include neutrino oscillations) is needed if the phenomenon is confirmed.

3. Identifying ν_e Events in MiniBooNE

MiniBooNE will search for $\nu_\mu \to \nu_e$ oscillations by detecting an excess of ν_e CCQE interactions in the detector. This signal process is identified by the spatial and temporal distribution of hits reconstructed in the photomultiplier array. For example, the muons emerging from ν_μ CCQE interactions produce Cherenkov ring distributions with cleaner edges than the electrons from ν_e CCQE interactions, which undergo multiple scattering in the medium.

The primary backgrounds to the oscillation ν_e CCQE interactions take two forms. The first are misidentified ν_μ events, primarily neutral current π^0 events. The photons emerging from the decay of the π^0 convert in the medium, producing an e^+e^- pair. If the photons are highly asymmetric in energy or have small opening angle, the photons will appear much like the primary electron emerging from a ν_e CCQE interaction. Otherwise, the two-ring topology of these events can be used to reject them. The particle algorithms incorporate parameters describing the ring sharpness and the overall profile to reject events with muon-like rings and multiple rings.
A second class of backgrounds come from interactions of ν_e intrinsically present in the beam from the decay of muons and kaons in the decay region. This background is irreducible; it cannot be distinguished in any way from the signal process apart from its overall energy distribution.

The expected signal and background rates, assuming $\Delta m^2 = 1\,\mathrm{eV}^2$ and $\sin^2 2\theta = 0.002$ and 10^{21} protons-on-target are shown in Table 1 with and without selection. The expected sensitivity using a fit to the energy spectrum of the expected events is shown in Figure 2.

4. Systematic Studies

In order to estimate reliably both classes of background in the analysis, a detailed understanding of both the neutrino beam and the detector performance is needed. A two-prong effort using offline measurements to complement detector data is in place to develop this understanding and reduce the systematic uncertainties.

For the misidentified ν_μ events, a precise estimate of the event rates in the detector and an accurate simulation of the detector response to these interactions is necessary. This allows accurate predictions of the performance of the particle identification algorithms used to identify the signal process. The experiment is currently undertaking a detailed study of the detector behavior using the detector calibration systems. Neutrino interactions observed in the detector, including the background ν_μ-induced π^0 production, are also being analyzed [10]. These *in situ* efforts are complemented by *ex situ* measurements of oil optical properties, including scattering, fluorescence and scintillation measurements [11].

MiniBooNE collaborators are active in the HARP experiment, where the kaon production rates needed to estimate the intrinsic ν_e background are being measured [12]. The latter measurements are cross-checked by the Little Muon Counter (LMC), a spectrometer that measures

Process	All Events	After Selection
ν_μ CCQE	553×10^3	8
ν_μ NC π^0	110×10^3	290
ν_μ $\Delta \to (n/p)\gamma$	1×10^3	80
Intrinsic ν_e	2.5×10^3	350
Oscillation signal	1.5×10^3	300

Table 1
The expected event yields for the primary background channels and the oscillation signal with $\Delta m^2 = 1\,\mathrm{eV}^2$ and $\sin^2 2\theta = 0.002$ and 10^{21} protons-on-target.

the spectrum and rate of wide-angle muon production resulting from kaon decay in the 50 meter decay region[13].

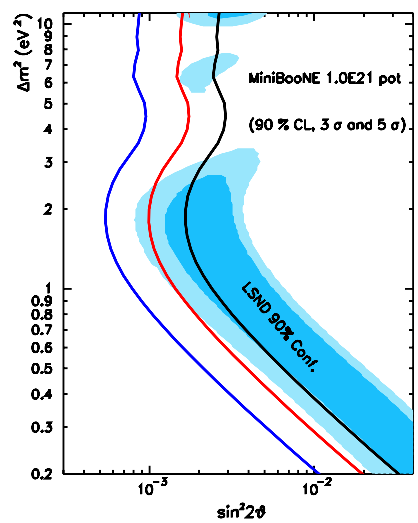

Figure 2. The expected sensitivity to $\nu_\mu \to \nu_e$ oscillations at MiniBooNE with 10^{21} protons-on-target delivered to the target.

5. Current Status and Outlook

The MiniBooNE detector has recorded nearly four hundred thousand neutrino interactions since data-taking began in 2002. During this time, the Fermilab Booster has delivered 3.66×10^{20} protons to the beryllium target used to produce the neutrino beam. The experiment is now accumulating the 10^{21} protons-on-target needed to make a conclusive confirmation or refutation of the LSND evidence for neutrino oscillations, while completing systematic studies necessary for reliably estimating signal efficiencies and background rates.

6. Acknowledgments

The collaborating institutions thank the Fermi National Accelerator Laboratory (FNAL) for its kind hospitality. We are grateful for the excellent performance provided by the Accelerator Division and the strong support of the Directorate of FNAL. This work is funded by the Department of Energy and the National Science Foundation of the United States.

REFERENCES

1. A. Aguilar *et al.*, Phys.Rev. **D64**:112007, 2001 (LSND).
2. Y. Fukuda *et al.*, Phys. Rev. Lett. **77**:1683-1686, 1996 (Kamiokande).
3. J. N. Abdurashitov *et al.*, Phys. Rev. Lett.**83**:4686-4689, 1999 (SAGE).
4. M. Altmann *et al.*, Phys. Lett. **B490**, 16, 1999 (GALLEX).
5. S. Ahmed *et al.*, Phys. Rev. Lett. **92**:181301, 2004 (SNO).
6. K. Eguchi *et al.*, Phys. Rev .Lett. **92**:071301, 2004 (KamLAND).
7. S. Fukuda *et al.*, Phys. Rev .Lett. **86**:5656-5660, 2001 (Super-Kamiokande).
8. S. Fukuda *et al.*, Phys. Rev. Lett. **85**:3999-4003, 2000 (Super-Kamiokande).
9. M.H. Ahn *et al.*, Phys. Rev. Lett. **90**:041801, 2001. (K2K).
10. H.A. Tanaka, these proceedings.
11. M. O. Wascko, DPF 2004, Riverside, California, USA, 2004.
12. I. Kato, these proceedings.
13. E. D. Zimmerman, 4th International Workshop on the Neutrino Beams and Instrumentation, Tsukuba, Japan, 2003.